STAFF SUMMARY SHEET

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1	DFB	sign	Putnam, O-6, 18 Apr 04	6			
2	DFER	approve	Solti, AD-22, 5 May 14	7			
3	DFB	action		8			
4				9			
5				10			

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Lt Col Maresh	DFB	333-3722	rwm	Not Applicable

SUBJECT	DATE
Clearance for Material for Public Release USAFA-DF-PA- 302	20140416

SUMMARY

1. PURPOSE. To provide security and policy review on the document at Tab 1 prior to release to the public.

2. BACKGROUND.

Authors: Westmoreland D (Associate Dean/USAFA).

Title: Teaching the Meaning of "Theory" in Science.

Release Information: This manuscript will be submitted for consideration for publication in the journal The American Biology Teacher.

3. DISCUSSION. N/A

4. VIEWS OF OTHERS. N/A

5. RECOMMENDATION. Sign coord block above indicating document is suitable for public release. Suitability is based solely on the document being unclassified, not jeopardizing DoD interests, and accurately portraying official policy.

Lt Col Ryan W. Maresh
Assistant Professor of Biology

Tab
1. Copy of manuscript

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TEACHING THE MEANING OF "THEORY" IN SCIENCE

David Westmoreland

Associate Dean, United States Air Force Academy

Professor of Biology

2355 Faculty Drive

USAFA, CO 80840

719-333-2469

David.westmoreland@usafa.edu

719 – 333-8533 (fax)

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ABSTRACT

There is increasing emphasis on teaching science as a way of knowing about the natural world. Central to this effort is fostering for students an understanding of the differences between facts, laws, and theories. Among these, the concept of a scientific theory is typically the most challenging to teach. Many students have a preconceived, colloquial notion of theories as purely speculative explanations that can be legitimately assessed by cursory examination. The exercise presented here engages students in the process of theory development and testing, thus clarifying the central role theories play in science.

INTRODUCTION

Science educators are increasingly aware of the importance of teaching science as a way of knowing and explaining the natural world, which requires that students comprehend the epistemological differences between scientific thinking and other approaches to understanding nature (Lederman et al. 2002). Part of this effort involves clarifying the cognitive elements of science (facts, laws, hypotheses, and theories) and the way they are incorporated to create a rational understanding of the natural world (Johnson and Peeples 1987). Typically, the greatest challenge to the instructor is to clarify the role of theories. Most students enter the science classroom with a firmly rooted, colloquial concept that scientific theories are mere suggestions - explanations that have not received rigorous testing, and do not necessarily have to be rational (Windschitl 2004).

A simple lecture approach is largely ineffective in correcting this misperception. The classroom activity presented here requires students to become directly involved in the development and testing of an explanation. While the theory development is outside the reach of a single classroom, this exercise parallels the process used in science for theory development. Consequently, it clarifies the vital role of theories in science.

METHODS

a. Materials needed. One Jenga game for each group of 3-4 students.

b. Teacher implementation. Prior to this activity, students need to have conceptualized the roles of facts and laws in scientific explanations. This requires a prior investment of time, typically a single lesson, in which the concepts of "fact" and "law" are established. A scientific definition of "fact" (for example, the fact that all birds lay eggs) is an observation that has been repeatedly confirmed, with no disconfirming instances (NCSE 2008). Laws are similar in that they are empirically verified, but they serve a different purpose in scientific explanations - that of describing relationships among interacting components (Lederman et al. 2002). For example, Boyle's law describes how pressure and volume relate to one another when matter is in a gaseous state. Laws are often expressed as mathematical relationships because they have high precision. But while facts describe the attributes of matter and energy, and laws describe their interactions, neither attempts to explain why certain facts and laws exist in the first place. Theories are causal explanations - efforts to explain why nature is the way it is.

A useful conceptual model is presented in Figure 1. Facts, represented by F's, are verified observations collected by the day-to-day workings of science. Laws describe how facts relate to each other. Theories are the broadest conceptual elements of science, here represented by a bag that encloses a large set of facts and laws, seeking to unify them under one explanatory construct. The teacher then poses a question to lead into the exercise: How are such an all-encompassing explanations constructed, and how are they tested?

c. Student instructions. Each group is given a Jenga set, and directed to start a standard game. Play continues for 3-5 minutes until typical Jenga towers have formed; the teacher stops the students before any towers collapse. Students are then presented with this scenario. They are anthropologists investigating an abandoned village where they note that many homes contain boxes with Jenga sets,

and that in several homes there are towers in various stages of construction, like the ones they have just created. In the first stages of scientific investigation, they collect facts – what are the facts that need to be explained? Students work in groups to compile a list of facts to be explained, and group lists are merged for the class as a whole. Table 1 contains typical observations that students make.

d. Theory development. The teacher repeats that the goal of science is to explain observations, not simply list them. Each team is challenged to creatively develop a theory that can explain all of the observed facts, with one caveat - the theory cannot incorporate the idea of a game. This requires that students step free of their prior knowledge, more realistically mirroring the challenge in science to explain a set of novel observations. This phase takes 5 – 10 minutes. I have been impressed with the remarkably creative explanations students develop (Table 1). As each group presents its theory to the rest of the class, the essence of scientific skepticism emerges – students begin to point out observations that are inconsistent or poorly explained. The teacher points out that this is exactly how the scientific process works. As theories are developed, there is careful attention to the facts that fall "outside the bag"; good theories can be modified to accommodate such facts, while poor theories that are incompatible with the expanding range of facts are discarded.

e. Testing theories. In the final part of the exercise, each group is challenged to produce an "If, then" prediction that can be used to test the theories that have survived their initial critical examination. Students are reminded that because falsification is an important aspect of science, predictions should be structured so that they are capable of falsifying the theory from which they originate. In other words, if, the prediction is not substantiated, the validity of the theory should be called into question. Examples of such predictions are presented in Table 1.

f. Summation. The teacher returns to the questions originally posed: How is a broad explanatory theory constructed? In most cases, by collaborative effort. The theory is an overarching

explanation for a set of observations, and sometimes laws, that seem to be related. Second, how can such a broad explanation be tested? The answer is that scientific theories generate new predictions that can be empirically evaluated. Good theories make testable predictions that turn out to be correct, while poor theories make testable predictions that turn out to be wrong. Far from being mere suggestions, theories are overarching explanations that are rigorously tested, and they unify facts that were previously unrelated. They are sometimes described as the fundamental goal of science. For this reason, saying "it's just a theory" to a scientist is tantamount to remarking "it's just a pamphlet" (in reference to the U.S. constitution) to a justice of the Supreme Court; "it's just a bunch of notes" to a composer; "it's just a string of binary numbers" to a programmer; or "it's just an anthology" to a theologian.

Evidence that it works. I have collected pretest/posttest data on student understanding of the nature of science for 4 semesters from students taking a general biology course or a capstone seminar course at the US Air Force Academy. The pretest and posttest are identical, posing 12 statements about the nature of science and assessing student opinion via a Likert scale. The three statements that assess student comprehension of the role of theory are presented in Table 2. With one exception, there is a consistent trend for comprehension to rise after the exercise described here.

REFERENCES

Johnson, R. L., & Peeples, E.E. (1987). The role of scientific understanding in college. *The American Biology. Teacher* 49(2), 93 – 98.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching* 39(6), 497 – 521.

National Center for Science Education. (2008). Definitions of fact, theory and law in scientific work. Available online at: http://ncse.com/evolution/education/definitions-fact-theory-law-scientific-work.

Windschitl, M. (2004). Folk theories of "inquiry:" how preservice teachers reproduce the discourse and practices of an atheoretical scientific method. *Journal of Research in Science Teaching* 41(5), 481 – 512.

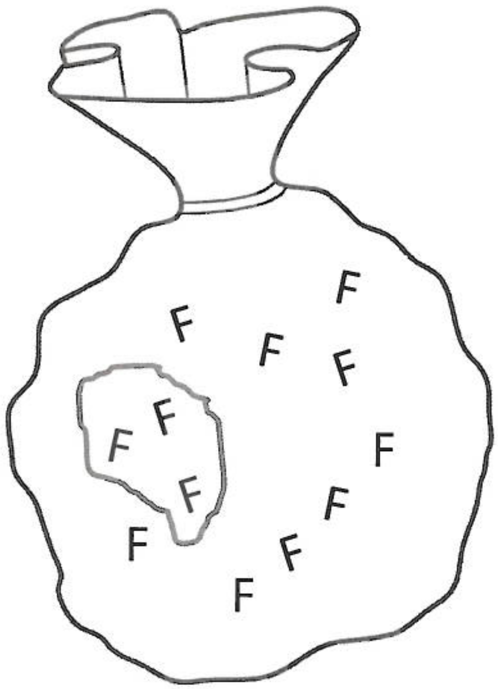
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Table 1. Typical development and testing of Jenga "theories". Column A lists the facts to be explained; Column B presents explanations that are typical of student groups; Column C gives predictions that, if incorrect, could falsify the corresponding theory.

Observed facts	Competing "theories" of Jenga	Predictions
The Jenga box is common in houses. In some houses the blocks are arranged into towers. When a tower is present, there is a box nearby. No two towers are exactly alike. Towers always contain 54 blocks. "Jenga" is written on the side of each block. All blocks have the same dimensions. There are more open spaces in the bottom half of the towers than in the top half. The towers have varying degrees of stability.	They record family histories. Blocks are moved in response to important family events – births, deaths, marriages. They are religious icons. The positioning of blocks corresponds to the completion of religious rituals. They are seismometers. Geologists use them to identify the epicenters of earthquakes. They are indicators of social status. The position of the blocks represent the family's perception of its place in broader society. They are a product of an architectural competition. Families were competing to win a contract for a new building.	Houses with larger families (as indicated by number of beds, range of clothing sizes, etc) should have more complex towers. The community should have one or more common meeting places where a replica of the tower is present. Houses with collapsed towers should be in the same vicinity. There should be a correlation with the apparent wealth of a family as judged by the quality and number of possessions and the complexity of the tower. There should be public advertisements for the Jenga competition.

Table 2. Pretest/post-test assessment of students' comprehension of the role of theory in science.

Statement	Section Enrollment	Number answering correctly: Pretest	Number answering correctly: Post-test	Improvement
1. The overarching goal of science is to collect as many facts about nature as possible. (Correct: disagree/strongly disagree)	7 20 21 57	4 16 7 29	7 17 11 40	57% → 100% 80% → 85% 33% → 52% 51% → 70%
2. A scientific theory is an educated guess about how to explain something. (Correct response: disagree/strongly disagree)	7 20 21 57	2 12 4 31	6 20 4 39	29% → 86% 60% → 100% 19% → 19% 54% → 68%
3. A theory is elevated to the level of law when it has been validated by repeated experiments. (Correct response: disagree/strongly disagree)	7 20 21 57	3 2 4 12	6 16 9 37	43% → 86% 10% → 80% 19% → 43% 22% → 69%